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UNITED STATES BUREAU OF MINES
SCOTT TURNER, DIRECTOR

INFORMATION CIRCULAR

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LIMESTONE

PART II. - DIMENSION STONE

BY

OLIVER BOWLES

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Part II. - Dimension Stone[1]

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FOREWORD

Bureau of Mines Information Circular 6723, entitled "Limestone: Part I.- General Information", discusses the origin and nature of limestone; shows production figures by States and uses; and describes in some detail the quarrying, preparation, uses, and marketing of crushed, broken, and pulverized limestone. Dimension stone, the other major branch of the limestone industry, is considered in this paper. Travertine, which is classed with limestone, is discussed in an Information Circular, in press, entitled "Onyx Marble and Travertine".

DEFINITION

Dimension stone is a general term applied to blocks of stone which with the exception of rubble and boulders are cut to definite shapes and often to specified sizes. The principal limestone products of this class are cut, carved, and roughhewn or scabbled blocks of building stone. Rubble, rough and irregular wall stone, is included with dimension stone because it is employed in masonry walls. Dimension stone is contrasted with crushed, broken, and pulverized products, which consist of irregular fragments sized chiefly by mechanical screening or air separation.

PRODUCTION

Table 1 shows production figures of dimension limestone by kinds over a series of years.

Table 1. - Dimension limestone sold in the United States, 1922-31

Year	Building stone[1]		Curbing, flagging, and paving		Rubble		Total value
	Cubic feet	Value	Cubic feet	Value	Short tons	Value	
1922	12,617,380	$12,418,873	(2)	(2)	286,340	$470,264	$12,889,137
1923	14,639,950	16,221,095	75,070	$46,830	327,180	484,771	16,752,696
1924	14,456,320	15,805,680	69,010	78,264	392,180	623,844	16,507,788
1925	15,983,800	16,092,079	129,730	98,587	324,630	513,387	16,704,053
1926	18,537,950	20,391,597	167,780	135,882	254,240	476,545	21,004,024
1927	17,340,690	18,820,045	223,370	134,360	226,280	400,790	19,355,195
1928	17,641,370	20,193,963	322,560	205,724	365,920	705,723	21,105,410
1929	17,864,700	20,649,257	471,880	158,266	352,480	693,678	21,501,201
1930	15,682,720	18,535,293	346,040	137,801	756,470	623,100	19,296,194
1931	11,706,840	10,858,697	166,260	85,175	229,510	296,426	11,240,298

1 Small quantities of monumental stone are included.
2 Included with building stone.

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It will be observed that the value of building stone amounts to 95 percent or more of the total value. Rubble, while used for building purposes, is classed separately. Material classed as building stone in this table may be subdivided according to its character and the extent to which it is manufactured into finished products. Table 2 shows the quantity and value of the various classes of building stone sold during recent years.

Table 2. - Building limestone sold in the United States by kinds, 1922-31

Year	Rough construction		Rough architectural		Finished (cut and sawed)		Total value
	Cubic feet	Value	Cubic feet	Value	Cubic feet	Value	
1922	210,690	$271,343	4,352,030	$2,577,416	5,843,550	$9,570,114	$12,418,873
1923	210,310	238,805	5,031,840	3,184,932	7,192,810	12,797,358	16,221,095
1924	239,680	304,911	5,012,520	3,231,613	6,751,930	12,269,156	15,805,680
1925	270,970	335,842	5,728,830	3,661,276	7,068,070	12,094,961	16,092,079
1926	288,700	380,131	6,161,390	3,837,081	9,015,090	16,174,385	20,391,597
1927	206,480	292,792	5,953,780	3,832,414	8,811,110	14,694,839	18,820,045
1928	211,780	279,434	5,255,690	3,268,140	10,655,180	16,646,389	20,193,963
1929	178,490	230,564	6,192,550	3,779,639	9,430,100	16,589,054	20,649,257
1930	131,410	194,550	6,134,250	3,278,346	7,936,770	15,062,397	18,535,293
1931	220,970	317,852	3,594,270	1,574,720	5,378,810	8,966,125	10,858,697

Rough construction stone, the first of the three groups of building stone in this table, is sold mostly by the ton for rustic building of many kinds. It overlaps to some extent the material classed as rubble in table 1.

Rough architectural limestone is sold principally to independent fabricating mills that buy rough stock from quarry companies. Material classed as finished stone is that fabricated in mills operated by quarry companies. Thus, the total value in the last column of table 2 is made up partly of rough-block and partly of finished-product values. This is unavoidable because the Bureau's statistics are based on sales made by the original producer. According to figures compiled by the Bureau of the Census, the total finished-product value of building limestone sold by fabricating plants in the United States in 1929 was $51,301,968 and in 1931, $24,142,920. These values are more than twice those shown in table 2. The difference is due to the added value of finished stone manufactured in independent mills.

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REQUISITE QUALITIES

While innumerable limestone deposits occur throughout the country, only a few consist of rock that will satisfy the exacting requirements of dimension stone. Deposits with irregular or closely spaced joints are not suitable because large blocks free from cracks or lines of weakness are generally demanded. Limestones display great variation in physical properties, such as texture, porosity, hardness, strength, and color, and upon these depend their adaptability and value as dimension stone. The chemical composition also varies in different types of stone, but while this may have some bearing on the quality of the material, it is of little consequence in this branch of the industry.

Dimension stone must have adequate tensile and compressive strength. Sound structural limestone suitable in other respects is almost invariably strong enough for any use; in fact, the strength of ordinary stone far exceeds the requirements for safety. However, it is generally conceded that rock disintegrates and weakens more readily when under severe stress, and therefore a factor of safety of 20 is demanded; that is, stone must be able to resist a crushing stress 20 times as great as that to which it will be subjected when placed in a wall. Tests of transverse strength - that required to sustain a load applied at the middle of a bar of stone supported at the ends - are more important than crushing-strength tests for dimension stone.

The suitability of a limestone depends to quite an extent on the degree of cementation of the grains. If they are loosely coherent the limestone is "earthy" or "friable". Material in which they adhere closely and strongly is "compact". Most limestones may be regarded as sufficiently durable for all ordinary uses, but the heavier or compact types are most desirable. Weight per cubic foot is a fair index of durability.

Hardness has a direct bearing on workability. While all limestones are soft enough to be scratched easily with a knife the presence of flint or other siliceous minerals may make quarrying or milling more difficult. For stone that is to be subjected to abrasion, such as paving, curbing, floor tile, or stair treads, hardness is a requisite quality, whereas it is not necessary in material used for walls or decoration.

For most uses uniformity of texture and color is preferable. Coarse texture was once regarded as a serious imperfection, but tests have shown that coarse-grained stone compares favorably in durability and strength with fine-textured material, and modern demands for variety have led to its wider use.

Limestones are of many colors, ranging from white to black. Colors other than white are produced by impurities in the stone. Certain constituent minerals, such as pyrite, marcasite, or siderite, may oxidize by weathering and cause surface stains which are serious blemishes. The colors of some limestones change with age, and while this is not always objectionable permanence of color is usually preferred. Choice of color depends on environment, individual taste, or prevailing fashion. Brown, buff, gray, or white limestones

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are usually chosen for building purposes. White and other light colors are not desirable for smoky cities. Variegated stone, sawed and rock-faced, is now popular for residences.

ECONOMIC CONDITIONS

A deposit of limestone may meet all the general requirements as to quality, but development may not be justified from a business standpoint. Availability of markets is an important consideration. Stone being a heavy product, the freight charge is a material part of the delivered price, and consequently a location within easy reach of large centers of building construction is to be desired. Transportation facilities, by truck, rail, or water, should be favorable. The best rates are obtained where two or more competing lines are easily accessible. Cost of production has definite bearing on market range, for a low-cost product can absorb a relatively high freight charge and thus compete successfully in distant markets with high-cost local stone. Quarry conditions should be considered carefully before development is undertaken. A thick overburden of soil or rock or a heavy flow of water requiring excessive pumping may constitute large items in the cost of production. Availability of labor, living conditions, and prevalent wage levels are other matters that deserve attention.

USES

Dimension limestone is used principally for building purposes. Its very limited employment for monuments, curbing, and flagging may almost be disregarded. Building limestone may be grouped into four classes of products - cut stone, ashlar, rough building stone, and rubble. The largest quantity consumed is in the form of cut or rough-hewn blocks.

Cut Stone

Cut stone includes all forms of finished blocks, columns, sills, moldings, balusters, or special designs. It is the most expensive type because usually the blocks are accurately shaped and sized in accordance with detailed drawings. Cut blocks may be used for entire buildings or only for certain parts, as window sills, trim, cornice, or base course. Massive blocks are used for bridges, dams, sea walls, and similar structures. Columns and balusters are used on both the inside and outside of buildings. For decorative purposes blocks may be elaborately carved.

Ashlar

Ashlar is a term applied to small rectangular blocks having sawed, planed, or rock-face surfaces. Several types are used. "Even-course" ashlar consists of blocks usually 3 or 4 inches thick of uniform height for each course, though succeeding courses may be thicker or thinner. They may be of uniform or random lengths. Two or more unit thicknesses may be used, several of the smaller sizes giving the same height as one of the larger blocks. "Random" ashlar consists of blocks that may be fitted together in a wall having irregular and unequally spaced joints.

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Ashlar is particularly adaptable for residences and is a much cheaper product than cut stone. Its production is also economically advantageous to producers, for small material that would otherwise be wasted may thus be utilized.

Rough Building Stone

Rough building stone consists of rock-faced masses of various shapes and sizes. It is used extensively for chimneys, basements, or entire walls of residences and to some extent for public buildings, bridges, fences, and the more ornamental types of retaining walls.

Rubble

The term "rubble" is generally applied to irregular fragments having at least one good face. It is the crudest form of building stone. Many years ago rubble constituted a distinct type of stone that was used principally for foundations and other rough walls, but concrete has gradually replaced stone for such types of construction. On the other hand, fashion in architecture was changing meanwhile from smooth and formal walls to rougher and more variegated styles, with the result that rubble has attained more dignified uses. From its lowly cellar-wall position it has been elevated to share with cut stone a more prominent place in many types of construction. Therefore, while rough construction stone and rubble were at one time fairly distinct types they are gradually merging, and it becomes increasingly difficult to differentiate them.

CENTERS OF PRODUCTION

Although limestone occurs in every State, deposits suitable for dimension stone or conditions favorable for their development exist in only about a half of the States.

Alabama is an important producer of oolitic limestone. Recent developments are chiefly near Rockwood where a large mill provided with the most modern equipment is operated. Shell limestones are quarried for building stone in Volusia and Pinellas Counties, Fla.

The largest quarry center for building stone in the United States is the oolitic limestone district near Bedford, Lawrence County, and Bloomington, Monroe County, Ind. In this district more than 20 large companies operate between 30 and 40 quarries and mills, and about 12 others operate finishing mills only. In 1930, exclusive of rubble and a small quantity of stone sold for rough construction, figures for which are not available, Indiana supplied 12,702,980 cubic feet valued at $16,186,172, or more than 81 percent of the total quantity and 87 percent of the total value for the United States. The total value as here shown does not include the value of finished products from independent mills. The 1930 figures are given because they are more typical of average conditions than those for 1931 or 1932. The Salem formation

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which provides the stone, is a massive bed ranging from 25 to nearly 100 feet in thickness. It extends from the Ohio River northward through Salem, Bedford, and Bloomington to a point north of Greencastle, a distance of about 125 miles. Buff and gray limestones predominate. The stone is easily worked when first quarried but becomes harder when seasoned.

Kentucky furnishes an oolitic limestone similar to the Indiana stone. It is quarried in Warren County and shipped to mills in Bowling Green for manufacture. Quite a number of quarries have been worked at various times, but only two have been operated during recent years.

A dolomitic limestone quarried principally at Mankato and Winona, Minn., is adaptable for heavy masonry, bridge construction, and building stone. An ornamental variety quarried at or near Kasota in the same State is widely used for interior decoration.

A pale buff to cream oolitic limestone is quarried for building purposes at Cedar Park, Williamson County, Tex. Other producing districts in Texas are Lueders, Jones County, and near Del Rio, Kinney County.

Limestone is also quarried for building purposes in a small way in Colorado, Illinois, Kansas, Maryland, New York, Ohio, Pennsylvania, Utah, and Wisconsin.

PROSPECTING

Development work should not be started on a deposit without reasonable assurance that an abundant supply of limestone suitable for dimension stone is available. Generally it is deemed unwise to expend the large sum of money necessary to establish quarries and finishing plants unless a reserve for at least 20 years' operation is assured. Core drilling is usually desirable for determining the extent and quality of a deposit. As quality may vary in different beds, each one should be tested. The essential features, such as color, grain, and extent of beds, can be determined from the cores. No definite rules can be given for the position or arrangement of prospect holes. In Indiana they are spaced 100 to 300 feet apart or closer in some instances. A log should be kept of the character of limestone found in each hole, and the cores should be marked and preserved for future reference. Depth of overburden may be determined by drilling or trenching.

QUARRY METHODS

Quarrying and milling methods discussed herein are those employed in the limestone district of Indiana, but they are essentially the same in other districts.

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Plan

Most deposits of limestone used as dimension stone are approximately flat lying and of limited thickness. Therefore, the stone available in any one opening may be removed within a short time and a new ledge uncovered. Ledges are usually 120 to 140 feet wide - a width that can be served with a derrick boom. In large quarries a series of derricks is set in line, and a long ledge is worked down in a succession of floors until all the good stone is removed. The line of derricks is then moved back 130 to 140 feet and another ledge begun; thus a whole area may be worked out in succeeding strips. Waste material from later operations is thrown into the openings previously made.

Stripping

In some places the overburden is stripped by power shovels. The hydraulic method is employed, however, when the surface contour is favorable for washing the soil into abandoned pits or other low-lying areas. This method is especially advantageous for washing clay from mud seams.

A second phase of stripping involves the removal of overlying noncommercial rock, which in some quarries may extend to a depth of 60 feet. The method of removal is governed chiefly by the nature of the contact of this rock with the underlying stone. Where it is separated by a layer of clay, shale, or a loose bed that serves as a cushion it may be drilled and blasted with light charges of low-grade black blasting powder with little danger of shattering the good material. However, where the rock overburden is continuous with the stone of good quality this process cannot be used, for powder cracks will extend into and destroy the good stone beneath. In such cases it may be necessary to channel the waste and remove it in block form - a stripping process almost as expensive as the removal of commercial stone. A unique process has recently been developed whereby a horizontal wire-saw cut is made at the base of the top rock. This artificial seam protects the stone beneath and permits removal of the top rock by blasting.

Channeling

Channeling machines make the primary cuts for block separation. The machine operates with a chopping action similar to that of a reciprocating drill, and cuts a channel or narrow trench on one or both sides as it travels back and forth on a 7-foot 2-inch-gage track. The edge of the cutting tool is 1-7/8 to 2-1/8 inches wide and makes a channel about 2 or 2-1/4 inches wide. Cuts are 8 feet 4 inches to 8 feet 5-1/4 inches apart and may be 8 to 12 feet deep and 50 to 100 feet long.

The cost of channeling ranges from 8 to 12 cents a square foot; it is, in fact, the largest single item of quarry cost and may amount to more than half the total cost.

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Wire Sawing

The high cost of channeling has led some operators to attempt more economical methods of cutting. At least two companies in Indiana are now using wire saws with fair success. One company made quite exhaustive tests in 1931. A cutting rate of 87 square feet an hour was attained, and the average cost was 15.9 cents a square foot. Details have been published by Newsom[3], who directed the work.

Key-block Removal

In opening up a new floor where no free face is present the removal of the first or key block is difficult. Sometimes it has to be broken up and removed as waste.

After an 8- by 8-foot block has been channeled on four sides the tracks are shifted and then two 2-foot blocks are channeled. The latter, known as "pulling" blocks, are usually comparatively easy to break loose by wedging in the channel cut. When a block is free, dogs or hooks are used to hoist it out. When one block is out of the way floor space is provided for removing succeeding blocks, which are wedged free at the floor and removed one by one.

Another method of starting a new floor is to remove a mass 2 feet wide along the wall and make a long cut 20 feet from the 2-foot space and cross-cuts 4 feet apart. After the pulling blocks are removed the 4- by 20-foot masses are turned down in the usual fashion.

Bed Lifting

Masses of rock that have been channeled are separated at the floor line by drilling and wedging. For this purpose a series of holes 8 to 12 inches deep and 1 foot to 18 inches apart is sunk with air-driven hammer drills. They are not made at right angles to the wall but are inclined at such an angle that wedges placed in them may be sledged conveniently. Wedges are placed in the holes and driven in succession until a floor break is made.

Turning Down Blocks

After a block is wedged free at the floor it is turned down in a horizontal position before further subdivisions are made. Two notches or dog holes are made in the back channel cut to accommodate massive hooks, which are connected by means of sheave and tackle to another pair of hooks secured firmly on the quarry floor some distance in front of the block. A heavy strain exerted on the cable by a derrick hoist gradually pulls the block over.

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3 Newsom, J. B., Results of Wire-Saw Tests: Trans. Am. Inst. Min. and Met. Eng., 1932, pp. 117-121.

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Large wedges may be sledged in the back channel cut to assist the process. Piles of loose rock, "pillows", are placed to break the fall so that the block comes to rest with little impact and without danger of breaking. Masses thus turned down are usually about 60 feet long, 12 feet high, and 4 feet wide.

Block Subdivision

The next step is to divide the mass into sizes for commercial use. Blocks are laid out with a carpenter's square and straightedge. Where two or more grades of rock are present longitudinal breaks are made between them. Holes are first drilled in line 6 to 8 inches deep and 12 to 18 inches apart. Fractures are then made by the "plug-and-feather" method. The "feathers" consist of strips of iron which are flat on one side for contact with the wedge and curved on the other to fit the wall of the drill hole. Two are placed in a drill hole, and a "plug" - a steel wedge about 6 inches long - is driven between them. They are sledged lightly in succession until a fracture appears. Blocks are commonly 10 by 4 by 3 feet and 10 by 4 by 4 feet.

Hoisting

Steel or wooden derricks of about 30 to 50 tons capacity are used for hoisting blocks from quarries. Derricks now in use have masts 80 to 110 feet high and booms 70 to 100 feet long. They are the swinging-boom type and are supported by 10 to 15 guy cables secured to deadeyes in the rock or attached to buried timbers. The end block is raised about 3 feet at the outer end and lowered again to the floor. This operation crowds it outward and makes a space of a foot or more for attachment of dogs. Heavy hooks (dogs) are inserted into the "dog holes" cut on opposite sides of a block, and a chain passed through the eyes of the hooks draws them firmly against the block, thus holding it securely for lifting. Blocks are removed in succession and placed on cars or piled for later disposal. Positions for attachment of dogs should be carefully chosen so that blocks may be exactly balanced. Each block is numbered or lettered to indicate its classification and for office records.

Storage and Transportation

Large storage capacity is essential, for enough stone must be accumulated during summer months to supply the demands of the four winter months when quarries are idle. Outdoor storage or "stacking yards" may be maintained at quarries or mills or at both places. A common method is to pile blocks within reach of derrick booms. They are usually piled high in a limited area, and it is sometimes difficult to sort them. Some operators prefer overhead-traveling-crane storage because the blocks may be handled more quickly. Standard railway cars and locomotives are almost invariably used for haulage.

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Scabbling

Quarry companies that operate mills use rough, untrimmed quarry blocks. If no local mills are operated, the blocks may be shipped long distances, and they must be trimmed carefully to avoid freight charges on waste. The trimming process is called "scabbling". Several methods are employed.

Scabbling picks similar to the ordinary double-pointed miner's pick are used to remove all irregularities. They are used also to remove corner masses from blocks to be turned into columns. Many operators prefer scabbling saws of various types because they leave a smooth, even surface and in a single operation remove large projections which by the pick method are taken off piecemeal. Diamond-tooth drag saws are used singly or in parallel pairs adjustable for width. Diamond-tooth circular saws cut rapidly and if mounted in pairs adjustable for spacing may scabble both sides of a block at one time. However, the depth of cut is a limitation; a 60-inch saw can cut only 26 or 27 inches and a 72-inch saw, 32 or 33 inches. This difficulty is overcome by making one pair of cuts to the maximum depth the saws will reach and then turning the block over and cutting from the reverse side. If the cuts fail to meet, the intervening rock may easily be broken.

Scabbling planers are effective substitutes for saws. They consist of two sets of massive vertical blades which scrape off irregularities as a block passes between them on a bed. By screw-feed adjustment the blades are set closer after each cut until a smooth surface is obtained. On blocks 6 feet high each cut removes one fourth inch of rock and on blocks 4 feet high one half inch. About three blocks may be scabbled in an hour by this method.

A wire saw consisting of a 3/16- or 1/4-inch 3-strand cable running as an endless belt driven by an electric motor is also used for scabbling. Several blocks may be lined up and cut at the same time. The equipment may be operated by one man, and an average cutting rate is 20 to 25 square feet an hour.

MILLING METHODS

Some limestone companies quarry only, others also maintain mills where the stone from their quarries is sawed into slabs or manufactured into finished forms, while still others operate only mills and buy their rough material for fabrication.

Drafting and Pattern Making

Before any cut-stone job can be started, accurate detailed drawings must be made of every piece of stone to be used that differs from another in size or shape. The cost of the drafting work required for a large structure may be one half to two thirds as much as the entire quarry expense of supplying rough blocks of stone. Architects' drawings usually are insufficient, for

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the stone must be fitted accurately to the steel framework, and detailed data on the size and position of each steel member are necessary before stone workers' shop drawings can be made. Some sizes may be duplicated many times in a building; others may be used only once or twice.

Patterns for molded and carved work are made of zinc or other soft metal, or sometimes paper patterns or stencils are used, the design being transferred to the stone surface by dusting burnt umber through perforations. For the most intricate carved work plaster models are used.

Ticket System

After shop drawings are made draftsmen prepare for every block of stone a ticket on which is a drawing of the block with exact dimensions indicated. The ticket is numbered, and if a pattern is to be used its number is also shown. The man in charge of gang sawing first gets the ticket and cuts the block or slab. As this passes to the planer, jointer, and all subsequent machines the ticket goes with it, and each workman consults it before any work is begun. By this means workmanship is constantly verified, and very few mistakes occur. Great care and skill are required, for one small error may ruin a block.

Block Handling

Mills are of two types. One is wide and equipped with two pairs of crane tracks. A heavy crane for placing quarry blocks on saw beds travels on one track; and on the other, a lighter and more rapidly moving crane for conveying smaller blocks as they pass from one operation to another. The crane almost universally used is the overhead traveling type with at least a 70-foot span.

The other type of mill is long and narrow with one pair of tracks on which several cranes operate. There may be a 25-ton-, 15-ton-, and a 7½-ton-capacity crane working at the same time. Most of them are of the 2-motor type, one motor with two friction clutches serving for both lateral motion and hoist.

Railway tracks for transporting quarry blocks to mills and shipping finished products enter across the end, down one side, or across the middle of the building. Rough blocks and single unfinished slabs are handled with grabhooks; finished and semifinished blocks or piles of slabs, with cable slings or with slings of rubber belting so as to avoid damage to corners and edges.

Operators travel back and forth in cabs attached to the crane. Two men called "hookers" attach and release hoisted blocks and signal the craneman.

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Sawing

The first step in manufacture is to saw rough blocks to requires dimensions. Gang saws of various sizes are used almost universally for this purpose. They consist of a series of soft steel blades set in parallel positions in a frame which has a backward-and-forward swinging motion. As the frame moves, actuated by a crank and connecting rod (pitman), the cutting blades lift toward the end of each stroke. This permits the abrasive, usually sand, to wash under them, and as they start back on the return stroke they bear down on the sand and abrade the rock rapidly. An adjustable automatic gear feeds the gangs downward at any desired rate. Steel shot is used as abrasive when a deeply scored, "ripple-mark" surface is desired. The average cutting rate is about 6 inches an hour. The blades may be spaced for thin slabs or thick blocks.

Another type, a straight steel blade with diamond teeth on the lower edge, is used as a drag-saw for making single cuts. A drag tooth is mounted with six diamonds of about 3/4-carat size placed in alternate positions on opposite sides of the cutting face. This saw will cut at a rate of 30 to 40 square feet an hour.

For making subsequent cuts circular diamond saws are almost invariably used. The blades are steel one fourth inch thick with a series of square notches around the rim. Steel teeth mounted with diamonds are set in the notches and held in place with copper rivets.

A heavy service type known as a "ripsaw" has a stationary mounting, and a bed actuated with a worm gear carries the block of stone beneath it. Teeth for ripsaws are supplied with two 1/2- to 5/8-carat diamonds. A jointing saw designed for smaller cuts and similarly mounted is provided with teeth, each having 6 to 10 small diamonds. A stream of water cools the cutting edge of a diamond saw and carries away the cuttings. The sawing rate is 3 to 16 inches a minute, depending on the depth of the cut. The most exacting workmanship is exercised in the manufacture of diamond circular saws to insure accurate balance, uniform cutting, and true running. Each saw is designed for a standard speed and should be run at no other. Speeds range from 11,000 to 13,000 surface feet a minute. With care a saw will perform constant service for 6 months to a year without being conditioned. Although the price of a diamond saw is high it cuts rapidly, and maintenance cost is low.

Silicon carbide (Carborundum) circular saws give excellent service for the smaller cuts because they leave smooth surfaces and are less liable than are diamond saws to chip the corners of blocks.

Planing

Planers are used for cutting stone blocks and slabs to smooth surfaces and desired thicknesses and also for cutting moldings and shaping curved designs. The frame that holds the cutting tool has lateral and vertical motion

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actuated by power-driven worm gear and may cut the tops and sides of a block simultaneously. As a block of stone is carried beneath a planer on a traveling bed called a "platen" at a rate of 30 to 45 feet a minute, the cutter scrapes a thin layer from the surface. Cutting tools are shaped to fit molding designs; that is, the tool is the reverse of the pattern.

When curved designs are to be cut the stone is placed on a second bed or platen resting on the regular planer bed and capable of rotating through an arc of a circle. This second platen is guided by an arm, pivoted to one side of the planer, whose length governs the curvature of the arc.

A Carborundum planer consists of two saws with a drum of smaller diameter between them. The saws trim the sides of slabs while the drum smoothes the upper surfaces. The planer bed travels at a rate of only 20 to 30 inches a minute but finishes the job in one cut, thereby accomplishing much more in a given time than an ordinary planer.

The accomplishment of a planer is equivalent to that of seven stonecutters using hammers, chisels, and modern pneumatic tools.

Turning and Fluting

Large columns are first scabbled to cylindrical shape and then mounted in lathes where they rotate against a tool traveling slowly back and forth over the full length of the stone. The tool is actuated by machine-driven worm gear and may be adjusted for any diameter by a screw feed. A smooth surface is obtained by this process, but final rubbing is usually done by hand.

The fluting process is also carried out on a lathe. The flutes are drawn with pencil or crayon on the surface of the column, and the fluting tool attached to the tool post of the lathe travels back and forth while the column remains stationary. This process is continued until the line bounding the flutes is reached. If a column is tapered the flutes may be cut shallower on the smaller parts of the column, and this automatically makes them narrower. When a flute is completed the column is rotated with a hand bar, and the process is repeated in the new position. The ends are finished with pneumatic tools, and the column is rubbed by hand.

For making balusters, particularly if many of one kind are to be fabricated, a Carborundum wheel cut as a negative of the pattern is generally used.

Milling

"Milling" is a term applied in a general way to all mill processes, such as sawing, planing, cutting, or carving, but it specifically refers to the operations of a milling machine by which irregular patterns are cut in stone. Milling is particularly advantageous in preparing for the carvers blocks in

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which deep recesses are to be cut, for it removes the bulk of the stone much more rapidly than do hand processes. The machine consists essentially of a rotating head which carries cutting tools of various sizes and shapes. It has right-and-left as well as vertical worm-gear motions, and a movable platen provides backward-and-forward motions.

Cutting and Carving

Cutting usually is defined as straight-line work and carving as curved work. Carving requires much skill and is generally done by experienced workmen. The work is now done for the most part with pneumatic tools - heavy ones for removing the larger fragments and smaller ones for completing designs, but a chisel and mallet are still necessary for certain operations. Patterns are used for the designs and models for the complicated figures.

Oolitic limestone may be carved more easily than most other building stones and therefore can be finished at a cost that permits of extensive use.

Finishing

Various types of surface finish are achieved by the use of different kinds of tools. A tooled surface, which is one covered with fine grooves in parallel lines, is made with a pneumatic or planer tool having fine teeth. A bush-hammered surface is rough and pitted, the hammer used having a face covered with small projections. A hand-picked surface is covered with indentations made with a sharp-pointed tool. A small-fluted surface is covered with small parallel corrugations. A four-cut surface is made with a planer tool having four corrugations to the inch. A rubbed surface is smoothed by hand-rubbing with sand and water or some other abrasive. A shot-sawed or ripple surface is deeply scored or grooved by using steel shot as abrasive for the gang saws. Chat-sawed stone is smoother than the shot-sawed stone.

COST OF QUARRYING AND MANUFACTURE

Quarrying and milling costs vary, as they depend on diverse conditions, such as depth of overburden, degree of hardness of the rock, type of equipment used, working efficiency, skill of workers, and size of operation. Approximate costs only may be given.

Quarry costs range from 20 to 30 cents per cubic foot of stone. Mill costs are extremely variable because only a little work is expended on some blocks and a great deal on others. Sawing slabs is expensive, costing 35 to 45 cents per cubic foot. Sawing in a second direction costs 12 to 15 cents more. Planing, milling, and cutting costs must be added for most products. Carving is also expensive. For jobs requiring a moderate amount of work, the total cost ranges from $1.50 to $2.50 per cubic foot. Columns or curved designs may amount to much more. Gothic carving may cost as much as $7.50 per square foot of surface carved.

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MARKETING

Dimension stone is sold by the cubic foot, and much of it commands a price sufficiently high to give it a Nation-wide market. From two thirds to three fourths of all building limestone is sold as rough blocks or sawed slabs to mills in consuming centers, where it is fabricated chiefly for small or moderate-size buildings. The balance of the production is manufactured for specific projects, usually of large size, in mills operated in conjunction with quarries or in independent mills. These mills, supplied only with shop drawings, can furnish for a structure many miles away thousands of blocks of limestone in exact dimensions, each fitted accurately for its particular position in the wall. The smaller limestone quarries for the most part sell their stone to local builders and contractors.

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